FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT ANP-10307P

"AREVA MCPR [MINIMUM CRITICAL POWER RATIO] SAFETY LIMIT METHODOLOGY FOR BOILING WATER REACTORS"

AREVA NP INC.

PROJECT NO. 728

1.0 INTRODUCTION

Topical Report (TR) ANP-10307P (Reference 1) describes the AREVA NP Inc. (AREVA) methodology for determining the safety limit minimum critical power ratio (SLMCPR) used in assessing thermal margin during operation of a boiling water reactor (BWR). The methodology described in the TR is an update of the SLMCPR methodology previously approved by the U.S. Nuclear Regulatory Commission (NRC) (Reference 2) and is currently supporting BWR operation. The SLMCPR methodology is being updated to incorporate an improved AREVA critical power methodology (Reference 3) and a realistic fuel channel bow model developed for the AREVA fuel rod thermal mechanical methodology (Reference 4). Both the new critical power methodology and the fuel rod thermal mechanical methodology have been reviewed and approved by the NRC. Incorporating these **[ ]** methods improves the predictive capability of the SLMCPR methodology while ensuring that adequate conservatisms are maintained.

2.0 REGULATORY REVIEW

In its regulatory evaluation, the NRC staff considered the applicable General Design Criteria (GDC), the licensee's use and application of NRC-approved methods, and limitations applied thereto.

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, Appendix A, GDC-10 states that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs).

Additionally, Section 4.4, "Thermal and Hydraulic Design," of NUREG-0800, Revision 3, "NRC Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," dated June 1996, states, in part, that the critical power ratio (CPR) is to be established such that at least 99.9 percent of the fuel rods in the core would not be expected to experience departure from nucleate boiling or boiling transition during normal operation or AOOs.

ENCLOSURE 1

The guidance provided by NUREG-0800 forms the basis for the NRC staff's review and ensures that the requirements of GDC-10 are met.

3.0 TECHNICAL REVIEW

3.1 Background

Operation of a BWR requires protection against fuel damage due to overheating of the cladding during normal operation and AOOs. For the purpose of establishing reactor operating limits, damage of the fuel rod cladding is conservatively assumed to occur if the fuel rod experiences boiling transition. Boiling transition is characterized by a degradation of rod surface heat transfer and a subsequent rise in cladding temperature. Protection of the fuel against boiling transition is a conservative approach that ensures cladding integrity is maintained during normal operation and AOOs.

The acceptance criterion related to boiling transition used as the licensing basis for currently operating BWRs is that the limiting value of MCPR is to be established such that at least 99.9 percent of the fuel rods in the core are not expected to experience boiling transition during normal operation or AOOs (Reference 5). The AREVA thermal limits methodology (Reference 6) is used to ensure compliance with this criterion. The thermal limits methodology and its relation to the SLMCPR methodology is briefly described below.

3.2 SLMCPR Methodology

As stated above, the SLMCPR is determined such that at least 99.9 percent of the fuel rods in the core are expected to avoid boiling transition if the core MCPR is greater than or equal to the SLMCPR. The SLMCPR methodology is determined using a statistical analysis that employs a Monte Carlo process that perturbs key input parameters used in the MCPR calculation. The Monte Carlo process is implemented by the three-dimensional Safety Limit (SAFLIM3D) computer program.

The SLMCPR methodology uses a critical power correlation to calculate the CPR for a fuel assembly based on the thermal hydraulic conditions and power distribution in the assembly.

Critical power correlations are based on theoretical models defining the functional dependence of critical power on assembly conditions. The coefficients for the correlation are developed based on extensive fuel assembly critical power testing. A critical power correlation is developed (or confirmed) for new fuel designs based on applicable test data. Critical power correlations developed for AREVA fuel designs and used in the SLMCPR methodology described in this report include the Siemens Power Corporation BWR (SPCB) correlation (Reference 7) and the ACE correlation (References 3 and 8). Other NRC-approved critical power correlations may be used with the AREVA SLMCPR methodology. Non-AREVA fuel that is co-resident during a fuel design transition is evaluated using a critical power correlation qualified by the process previously approved by the NRC (Reference 9).

Because the SLMCPR methodology provides the ability to evaluate the number of rods in boiling transition for a specified MCPR, the method can be used to assess the number of rods that fail due to cladding overheating during infrequent events or accidents.

3.3 Improved Features

The improvements incorporated in the SLMCPR methodology described in the above stated TR are summarized below.

- Full Implementation of the ACE Critical Power Correlation

The ACE/ATRIUM-10 and the ACE/ATRIUM 10XM critical power correlations use more detailed power distribution data than required for previous correlations. As described in the approved ACE/ATRIUM-10 correlation TR (Reference 3), the correlation is implemented in a conservative manner, that is, it includes all associated uncertainties, within the currently approved SLMCPR methodology. In addition, the SLMCPR methodology has been revised to obtain more detailed power distribution data from calculations performed using the MICROBURN-B2 computer code (Reference 10).

The ACE correlation uses a **[ ]** that improves the prediction of critical power. With new fuel designs, AREVA will continue to use the same form of the ACE correlation with coefficients based on test data applicable to that fuel design. Once ACE is approved for application to a new fuel design, its use within the SLMCPR methodology is implemented. The same form of the ACE correlation is retained for the ATRIUM 10XM fuel design that is planned for introduction in the U.S. plants (Reference 8).

- Incorporate Realistic Fuel Channel Bow Model

The MCPR safety limit is sensitive to power profiles. In addition, power profiles (power shape distributions) are impacted by channel bow. As a result, the MCPR safety limit is impacted by channel bow. Consequently, AREVA developed a realistic model to predict fuel channel bow as part of the recently approved AREVA fuel rod thermal mechanical methodology for BWRs (Reference 4). The realistic channel bow model is implemented in the MICROBURN-B2 computer code, and the SLMCPR methodology has been revised to use the MICROBURN-B2 computer code.

The channel bow model was implemented in the MICROBURN-B2 core simulator to account for channel bow effects on the realistic power histories used in the statistical fuel rod methodology (Reference 4). AREVA developed a channel growth correlation to determine the magnitude of the channel bow. The model is based on operating experiences and experimental channel bow measurements.

The current AREVA SLMCPR methodology conservatively assumes that each and every assembly in the core experienced the most adverse channel bow condition simultaneously, and applied the most conservative uncertainty for a rod in each fuel type to all rods of that fuel type (Reference 2). The use of MICROBURN-B2 makes possible the characterization of the impact of channel bow for each node of each rod in the core, thus forming a much more detailed calculation.

- Expanded Coupling with MICROBURN-B2

The implementation of the ACE critical power correlation and the realistic channel bow model required additional data from MICROBURN-B2. Consequently, the expanded coupling with MICROBURN-B2 facilitated other improvements to the SLMCPR methodology.

AREVA used the **[**

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within the updated SLMCPR methodology.

The thermal hydraulics conditions, reflecting the core operating conditions and power distributions for each fuel assembly are obtained directly from MICROBURN-B2. These thermal hydraulic conditions reflect the core operating conditions and power distribution assessed in the SLMCPR calculations. This provides the best representation of the conditions in each assembly in the core and is consistent with the core monitoring system.

The MICROBURN-B2 core simulator computes the maximum channel bow magnitude for each assembly, consistent with the correlations described in Reference 3. The assembly maximum bow is then used to determine the axial bow profile as a quadratic function with its peak at the axial mid-plane and with zero values at the top and bottom of the channel.

3.4 Application of the Channel Bow Model within the MCPR Methodology

3.4.1 Channel Bow Model within the SLMCPR

The assessment of channel bow within the SLMCPR methodology is accomplished by **[**

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The MICROBURN-B2 channel bow model and uncertainty described in Section 2.2.1 of ANP-10307P, Revision 0, is applicable for typical reload cycles, that is, normal channel bow situations. For non-typical situations, such as abnormal channel bow situations, transition cores, and new channel designs, the channel bow model will be applied in a conservative manner through use of **[**
] according to NRC approved methods (Reference 4).

3.4.2 The **[** **]** Interface

Due to the large computational requirements by MICROBURN-B2, AREVA **[** **]** The execution **[** **]**

3.4.3 MICROBURN-B2 Interface

In addition to the interface between MICROBURN-B2 and **[** **]**

SAFLIM3D receives MICROBURN-B2 information directly and **[** **]** The information pertaining to channel bow uncertainty is obtained **[** **]** **[** **]** Thus, the axial power distribution is fully known for each assembly in the core.

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4.0 CONCLUSION

In summary, TR ANP-10307P describes the process for the determination of the SLMCPR. The process includes the calculation of MCPR using the same method as used by the core monitoring system. The SLMCPR is established using a design-basis power distribution and a statistical convolution of the measurement and calculation uncertainties associated with the determination of MCPR. The impact of fuel channel bow on power distribution is included in the calculations. The SLMCPR, in conjunction with reactor transient and event analyses, establishes an operating limit on MCPR that ensures that the fuel rod cladding integrity is preserved during normal operation and AOOs. The NRC staff finds TR ANP-10307P, Revision 0 acceptable for use as a reference for plant-specific licensing actions.

5.0 REFERENCES

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4. BAW-10247PA, Revision 0, "Realistic Thermal Mechanical Fuel Rod Methodology for Boiling Water Reactors," AREVA NP Inc., April 2008.

5. NUREG-0800, Revision 6, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," NRC, March 2007.

6. XN-NF-80-19PA, Volume 3, Revision 2, "Exxon Nuclear Methodology for Boiling Water Reactors, THERMEX: Thermal Limits Methodology Summary Description," Exxon Nuclear Company, January 1987.

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